PROCESS OF USING SODIUM SILICATE TO CREATE FIRE RETARDANT PRODUCTS

This application is a non-provisional application claiming the benefit of provisional application serial number _____ (filed March 15, 1996, in the names of Karen M. Slimak and Robert A. Slimak, entitled "USING SODIUM SILICATE TO CREATE FIRE RETARDANT PRODUCTS") and provisional application serial number _____ (filed March 14, 1997 in the names of Karen M. Slimak and Robert A. Slimak, entitled "Effectiveness of Sodium Silicate and Micro-layers of Silicon oxide glassy films in imparting fire retardant properties and moisture resistance to cellulosic materials) the entire disclosures of which are being incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The purpose of this invention is to provide 1) sodium silicate (water glass) impregnated wood materials introducing a fire retardant property to wood products, 2) water glass impregnation of other materials, such as paper and cloth, in such a way as to allow their intended functions while reducing the risk of flammability, and 3) wood products treated with sodium silicate can be used simultaneously to impart flame resistant properties to wood and to cause the wood to become termite resistant, providing an environmentally friendly method for long term termite control.

Liquid sodium silicate (water glass), applied to the surface of various products, can impart fire retardant properties. In the presence of fire, the sodium silicate will form foam-like crystals that help to provide an insulating barrier between the product and the flame, and will thus slow down the spread of fire. Wood and other products will become less flammable when treated with sodium silicate. The foam-like product produced appears to be more than a mere change in form of the sodium silicate. It is believed that the foam-like material is the product of a chemical reaction, and also imparts fire retardant properties to the material treated with sodium substrate.

2. Description of the Related Art

Throughout history, house fires have been a major threat to the well-being of many families. I know what this feels like first hand. Last year, my house was ravaged by a house fire, and I want to prevent other families from having to go through what I went through. The idea for this invention came to me. My sister was using water glass to glue glass planes together to make test chambers for her science fair project. I wondered if it was possible to coat wood with water glass and help make the wood fire retardant. As I watched her work with the water glass, I played around with it and coated small pieces of wood and noticed that when the pieces were applied to a very hot flame, the water glass bubbled over forming a natural barrier against the flame. Thus, it appeared to me that as the sodium silicate formed bubbles, the wood remained unaffected by the flame.

A fire retardant material is one having properties that provides comparatively low flammability or flame spread properties (ASTM 1992). There are a number of materials that have been used to treat wood for fire retardancy including ammonium phosphate, ammonium sulfate, zinc chloride, dicyandiamide-phosphoric acid and sodium borate. Solutions of these fire-retardant formulations are effective when injected into the wood under pressure (Condensed Chemical Dictionary 1971). The sodium salts of silicon, or water glass, however, have not been identified as a fire retardant. If my hypothesis is correct, that water glass is an effective fire retardant when applied as a coating, then it could be an important finding since it is virtually non-toxic, safe to use, relatively cheap, readily available and can be easily used by the homeowner.

Sodium silicate (water glass) is a member of the family of soluble sodium silicates and is considered the simplest form of glass. The formula varies from Na_2O_3 SiO_2 to $2Na_2OSiO_2$ depending on the proportions of water. The composition used in this study was a 40 percent concentration. Water glass is derived by fusing sand and soda ash; it is noncombustible with

low toxicity. It is used as catalysts and silica gels; soaps and detergents; adhesives; water treatment; bleaching and sizing of textiles and paper pulp; ore treatment; soil solidification; glass foam; pigments; drilling muds; binder for foundry cores and molds; waterproofing mortars and cements; and impregnating wood. The latter use, however, has not been linked with fire retardancy (Condensed Chemical Dictionary 1971).

The terms used with flame-resistant materials are sometimes confusing. Fire resistance and flame resistance are often used in the same context as the terms fireproof or flameproof. A material that is flame resistant or fire resistant does not continue to burn or glow once the source of fire has been removed, although there is some change in the physical and chemical characteristics of the material. Fireproof or flameproof refer to material that is totally resistant to fire or flame, such as asbestos. Most organic material like wood undergo a glowing action after the flame has been eliminated. This "afterglow" may cause as much damage as the flaming itself.

The mechanisms of fire-retardancy are complicated. The coating theory reveals that fire resistance is due to the formation of a layer of fusible material which melts and forms a coating, thereby excluding the air necessary for the flame to propagate. This theory, first reported by Gay-Lussac in 1821, was the basis for the development of fusible salts such as carbonates, borates, and ammonium salts. The gas theory theorizes that the flame retardant produces noncombustible gases which dilutes the flammable gases. The thermal theory suggests that the flame is dissipated by an endothermic change in the retardant and the heat supplied from the source is conducted away from the wood so fast that combustion temperatures are never reached. Chemical theory says that the strong acids and bases (water glass is a strong base) impart some degree of fire retardancy (Concise Encyclopedia of Chemical Technology 1985).

My theory, and the basis for my invention is that sodium silicate can make wood and other products fire retardant. The sodium silicate will enter the voids in the wood, and harden into glass. The sodium silicate will separate the wood fibers from one another, and not allow burning. Any flame applied to the samples will not burn or spread, because it comes in direct contact with the sodium silicate. The preliminary observations I made on my own with sodium silicate and small pieces of wood showed that when in contact with a very hot flame, the sodium silicate bubbles over, forming a natural barrier against the flame and the wood remains unaffected by the flame.

To test my theory, I decided to treat (by dipping and soaking) dimension lumber with different concentrations of water glass and to burn the treated products with a propane torch to determine the potential for fire retardancy.

Summary of the Invention

Dimension lumber (1"x4"x12" pine and 2"x4"x12" spruce), 1"x4"x12" pressure treated pine samples and composite materials were treated with sodium silicate by dipping (a 24-hour exposure) and soaking (a 7-day exposure) in water glass. Paper and cloth samples were similarly treated. The samples were then air dried at room temperature for a minimum of seven days. To test for fire retardancy, the wood samples were subjected to a hot flame from two propane torches for 20 minutes, and the paper and cloth samples were subjected to a candle flame. Data on flame propagation, afterglow, ash development and weight loss were collected during and after the burns. To measure variability, four replicates of each sample were burned along with an untreated sample (a control), and a sample treated with sodium borate, a known fire retardant chemical.

Detailed Description of the Invention

Treating the Samples with Water Glass

Dimension Lumber. Pieces of kiln-dried 1"x4" pine dimension lumber, 2"x4" spruce dimension lumber, and pieces of 1"x4" pressure treated lumber were placed in plastic tanks (dimensions 2 ft x 1 ft x 8 in) filled with water glass solutions to a depth of 6". The pieces were placed in the tank in such a way that they were completely submerged and yet not in direct contact with each other. For the "Soak-Treated" lumber, the pieces remained in the treatment tanks for seven days after which time the pieces were removed from the tank and placed for seven days on a drying apparatus designed to keep the wood pieces from touching all but very small occasional supporting points. The borax treated sample was prepared similarly using a saturated aqueous solution consisting of seven (7) parts of sodium borate (Borax) and three (3) parts boric acid, by weight. The controls were not treated. The wood was weighed before and after treatment with the fire retardants. The same procedures were used for the "Dip-Treated" wood except the wood was submerged in the solutions of fire retardants for only 24 hours.

Composite Materials. Pieces of wafer board, plywood and particle board were made and then treated with water glass. For the wafer board and the particle board, sawdust or wood shavings were mixed with 100% water glass until the mixture was damp, thoroughly wet, and compressible. Then portions of the mixture were compressed in a form under pressure for approximately 24 hours. The water glass-wood composite materials were removed from the forms and allowed to dry for seven days. The plywood was made from balsa wood which was soaked for seven days in 100% water glass. Then the pieces were assembled in 5 layers with alternating grain patterns to form a final plywood sample 3" x 9"x 1/2". The plywood was dried under pressure using clamps for seven days to achieve the

desired shape and density. The borax treated samples were prepared similarly using a saturated aqueous solution consisting of seven (7) parts of sodium borate (Borax) and three (3) parts boric acid, by weight. The remaining controls were not treated. The wood was weighed before and after treatment with the fire retardants.

Cloth samples: Eight pieces of water glass-impregnated cloth test pieces were each made by combining 50 g water glass and water, 200 g water and laundry lint. The mixture was spread thinly on a screen and dried for seven days. The product was a felt-like material 4 in x 12 in. For the control cloth test pieces were made as described above without the inclusion of water glass. Two additional test samples were prepared by combining laundry lint and water and adding a saturated aqueous solution consisting of seven (7) parts sodium borate (Borax®) and three (3) parts boric acid, by weight, in amounts suitable to form a finished cloth product, and then drying. Another untreated control was also used.

Paper samples:: Eight pieces of water glass-impregnated paper test pieces were each made by combining 50 g water glass and water and 200 g water and 6 sheets of pulverized paper. The mixture was spread thinly on a screen and dried for seven days. The product was a coarse paper material 4 in x 12 in. The untreated control was made without water glass. Two additional test samples were also prepared by combining pulverized paper and water and adding a saturated aqueous solution consisting of seven (7) parts sodium borate (Borax®) and three (3) parts boric acid, by weight, in amounts suitable to form a finished paper product containing borax, and then drying.

Termite Reaction to Water Glass Treated Samples

Termites: Thirty small pieces of wood, 0.5 in on a side, were treated with water glass as described above for 100% water glass with a seven day soaking period and subsequent seven day drying period. Other pieces of wood, of identical size, that are not water glass treated were used as controls. Thirty pieces of water glass treated wood cubes were placed in each of a 1-quart glass test chamber. A second test chamber contained only untreated wood cubes. Worker termites and moist paper towels were added to each container to form a suitable terrarium environment. Termite activity was be observed for 2 months.

Burn Testing

High-Temperature Propane Burn Tests: Both the treated and untreated wood was subjected to a high-temperature flame supplied by a "Bernz-O-Matic" 400 gm propane fuel cylinder with a JT-680 tip (Model TX-9). The wood was suspended vertically, side-by-side, approximately 10 inches apart from a metal rack made from copper tubing and designed to burn six (6) pieces of wood simultaneously. Each "burn" event consisted of burning six pieces of wood: four (4) treated pieces; one (1) piece treated with sodium borate, and one (1)

piece of untreated wood. The untreated and sodium borate treated pieces served as controls. During each burn event, flames from two propane torches, one in front and one in back of each piece of wood and each slightly offset in opposite direction from the center, were directed at the down-side edge of the suspended wood. The burn event was divided into three periods: burn initiation (T_0), burn period ($T_{1:20}$), which lasted 20 minutes, and post burn period ($T_{20:35}$) when observations were continued 15 minutes after the torches were turned off. Observations such as amount of flame produced, flame spread or propagation, area of burn, amount of after glowing, percent of wood burned and weight after burning were recorded on data sheets. Each burn event was also recorded on a video camera.

The method described here for testing the combustible properties of treated wood is a departure from the standard test method recommended by the American Standards and Testing Methods (ASTM). Standard method E 69-95 (ASTM 1995) describes a method where the combustible material is placed in an apparatus known as a "fire-tube assembly" and measurements similar to that described above are made. The fire-tube apparatus can only accommodate a small piece of wood, 3/4 in x 3/8 in x 40 in in length, which is much smaller than the pieces in this study, and can only burn one piece of wood at a time. I wanted to experiment on pieces of wood that were about the same size as wood commonly used by homeowners and I wanted a side-by-side comparison between treated and non-treated wood. The fire-tube apparatus is also not readily available. The measurements called for by this standard method, however, are essentially the same as those taken during this study.

Candle Tests: The cloth and paper samples and the sodium borate/boric acid treated and untreated controls were each placed in a flame test chamber and tested as described above for the propane flame test with the exception that the flame was from a 5 in candle. The flame was directed at the bottom of the test samples throughout the test period.

In addition water glass treated samples of 2x4 dimension lumber were subjected to candle flame for 1.5 hours. The nature of burn patterns were in comparison to those of untreated controls.

Figure 1. Procedure for Studies of Fire Resistance in Products Treated with Sodium Silicate

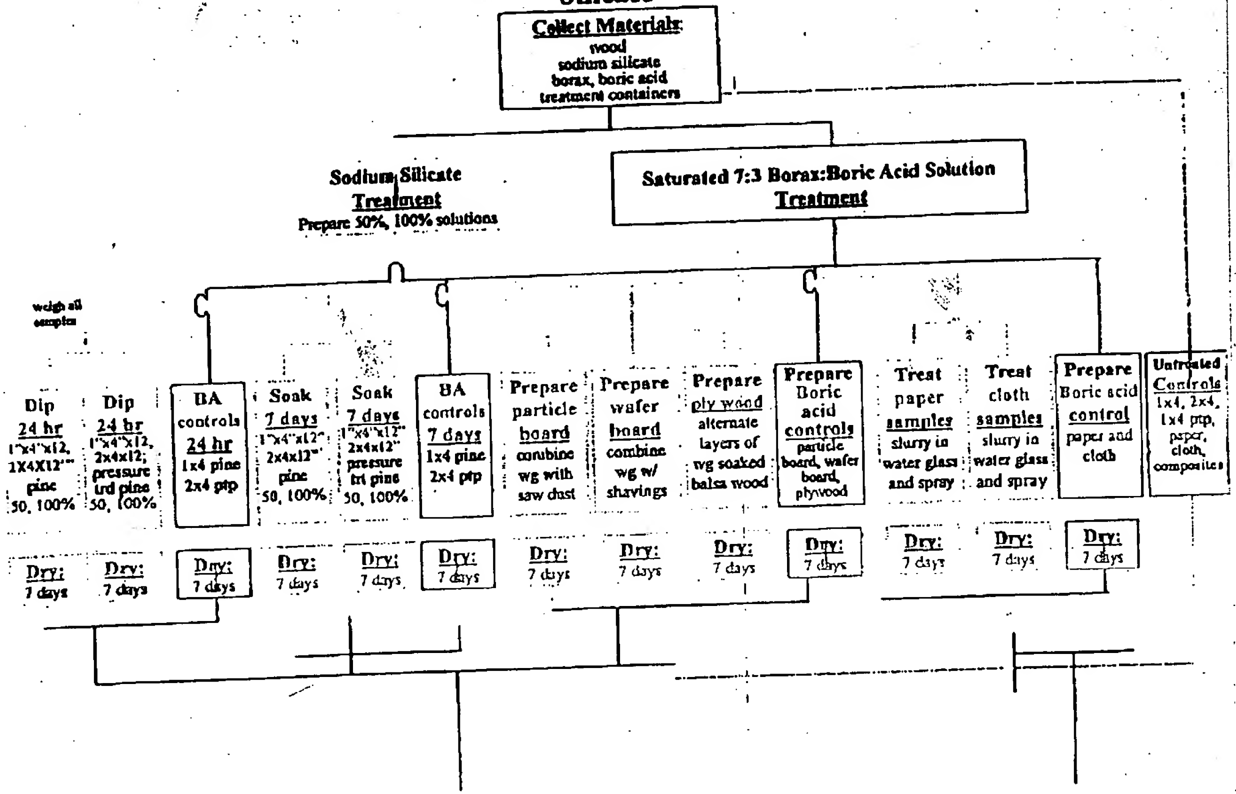
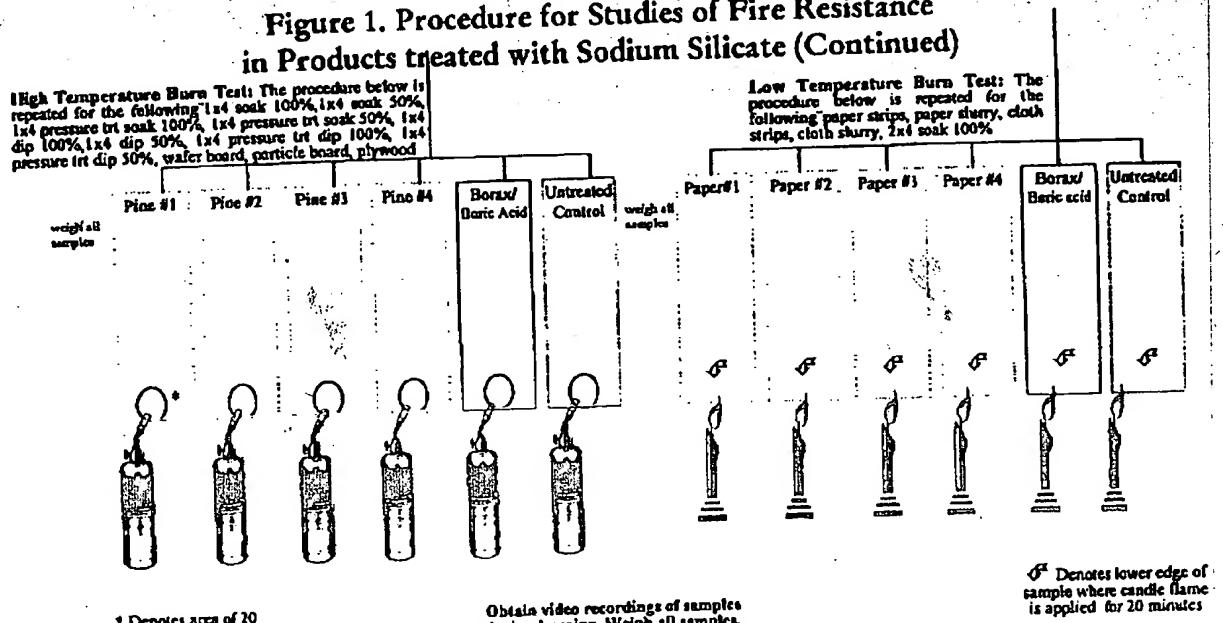


Figure 1. Procedure for Studies of Fire Resistance in Products treated with Sodium Silicate (Continued)



RESULTS

1X4 PINE - PROPANE FLAME TESTS:

Figures 2-4 present the results of propane flame tests of sodium silicate treated 1x4 pine samples.

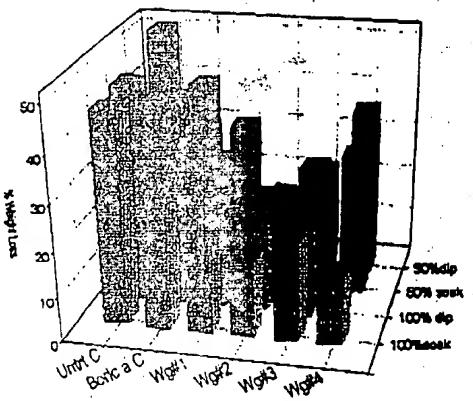


Figure 2. Weight loss of samples in flame tests with 1x4 dimension lumber

There is a large difference between the untreated control and the test samples. With the untreated controls there ranges from about a 40-38% wt. loss to 50% wt. loss, and with the treated samples, it ranges from about 15% wt. loss to a 25% wt. loss. As Figure 2 shows, the boric acid test samples have a much greater average % weight loss than the treated samples. This three dimensional set of bar graphs shows how great the difference is with each bar graph colorized and labeled.

Propane Flame Test for 1x4 pine wood sample subjected to a seven-day soak in 100% sodium silicate:

Burn initiation (T_0): The propane flame from the nozzle contacted the wood in an area extending 7 cm laterally and reaching up approximately 27.5 cm. In the first few seconds the flame color was light blue, and relatively difficult to see. In the impact area, the wood began glowing in a small circular area approximately 1 inch sq. Immediately after this, flame color changed from light blue to yellow orange, presumably due to the presence of sodium in sodium silicate traveled outward and upward along a curving line from the initial contact point.

Burn period (T_{1-19}): During this period, the fire continued to remain in the pattern described above, with occasional sparks. The flames did not migrate beyond the flame contact area; however the lower half of the flame contact area was charred. The area at the top edge of the flame flickered orange and below this area the flame was yellow-white in color.

Post burn period (T_{20-33}): After the propane flame was extinguished, the flames died down within 5 seconds; however hot, red glowing embers were observed in the 1 in square area where the heat and flame reached the highest temperature. These embers continued to glow and smolder for approximately 15 minutes. After the embers had cooled a hole, approximately 1 in square was observed at the point of most intense flame application.

On the sides of the wood, white foam bubbled out from the water glass, traveling up the edge of the face of the wood. This area of white foam prevented the spread of flame and char laterally to the side of the wood. One face side of the sample was 83% covered with char and soot. The other face side was 50% covered with char. The color of the char was black, with a thin layer of white foam on the top. There was less cracking of the char than was found on the control. The small sides of the wood remained untouched by either char or fire. The area above the flame reflection took place, had a thin layer of soot in which the underlying wood was unburned. The foaming of the sides took place much greater on the left side of the wood than on the right side. The left side foamed about 90% more than on the right side of the wood. There was observed 0-1% of the small sides burned or charred during the test.

Propane Flame Test for 1x4 pine wood untreated control sample, compared to 1x4 soak, 100% sodium silicate:

Burn initiation (T_0): The propane flame from the nozzle contacted the wood in a 4 cm diameter, then fire spread up the wood in three lines: one in the center of the sample, and the other two growing up the sides. The flame extended 10 cm from the initial point of contact.

Burn Period (T_{1-30}): After two minuets of burning, the flame began to die down to only extending five cm from the initial point of contact. When three minutes and thirty-five seconds had passed, new larger nozzles were added to the tank to increase the amount of fire being applied to the wood. The flame from the larger propane nozzles extended to the top of the wood sample and above it, totaling 29 cm at the greatest height. The flame spread to all sides of the wood, but the small right side received the most amount of fire.

Post Burn Period (T_{30-35}): After the propane tanks were removed from the wood sample, the flames died down within five seconds, leaving two large holes with the outside edges smoldering. The area where the glowing embers were observed was in a ring of about 2 cm around the large hole. There were two large holes in the sample after the burning was finished. The large hole was 8 cm long and 5 1/2 cm wide. The smaller hole was 2 cm long and 4 cm wide. Char extended all of the of the wood that had been above the initial point of contact. The char is dark black to dark brown. The area where the char is has many cracks in it, extending throughout all of the char area. The small left side of the wood is 15% covered with char; on the right side of the wood, the side is 35% covered with char. The char has a layer of soot over it, and rubs off on skin, clothing, or any other casual contact that may occur.

Propane Test for 1x4 pine wood sample subjected to a 1-day dip in 100% sodium silicate:

Burn initiation (T_0): The flame from the nozzle of the propane tank contacted the wood at the bottom of the sample. The flame began to redden an area of 3 cm^2, then the flame began to reflect off the wood, with the flame extending 6 cm from the initial point of contact.

Burn Period (T_{1-20}): During this period, the flame reflected off the wood sample. The flame itself did not propagate onto the wood sample. The total height of the flame was about 6 cm high and 3 cm wide. The tops of the flames flickered in the wind. The sound that the wood made when it was being burned in a new area was that of a sizzling, and occasional popping one. A layer of thin

char, or soot grew up the wood above the flame. The layer of ash continued to grow up to the top of the wood. After 10 minutes had passed, the flame died down to a small cinder area around the initial point of contact.

Post Burn Period (T_{20-35}): After the flames from the propane tanks were removed, the flames on the wood died down in a matter of seconds. There were glowing embers around the area where the propane tank had been. The area was 5 cm tall and 6 cm wide at the widest point. The wood is 50% covered in char. The color of the ash is from black to dark brown, except for a layer of white sodium silicate byproduct on top of the char and ash in some areas. Along the sides of the wood there is bubbling from the sodium silicate. The bubbling is 90% greater on the left side than on the right. There is not much charred area on the sides; only about 10% of the sides are burned. There is no burning, charring or soot on the back side of the sample.

Propane Flame Test for 1x4 pine wood untreated control sample, compared to 1x4 dip, 100% sodium silicate:

Burn initiation (T_0): When the flame is first applied to the test sample, flame begins to climb up the sides of the wood, reaching 20 cm off the original burn point. The flame began to slowly travel up the sides of the wood, scorching it and spreading soot and char around the burn site.

Burn period (T_{1-20}): The flame continues to rise 12 cm up the left side of the wood sample. The flame adjusts to the middle of the sample, burning up the sample about 13 cm. The flame chars 70% of the wood, as it buns in the center. The top of the flame flickers and wavers in the wind.

Post burn period (T_{20-35}): The wood sample smolders and burns when the propane tanks are removed. The area of char on the wood extends from the bottom of the sample, to 6 cm below the top of the wood. The fire charred half of the right side of the wood, and over 75% of the left side. In the sample, there were large craters in the wood, where the flame had not eaten all the way through the wood. The craters were: 6 cm x 4 cm, and 5 cm x 3 cm. The area where the burning took place had large cracks in it, the area where the cracks were extended all the way that the flame did. The top part of the sample that was untouched by flame is covered in a thin layer of soot and ash. The color of the char is a dark black to a dark brown.

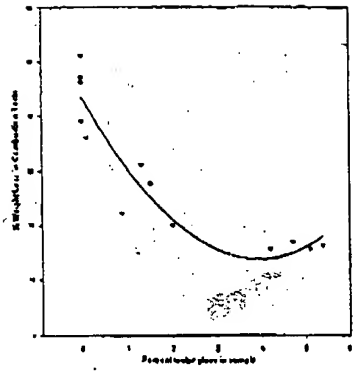


Figure 3. Comparison of weight per cent water glass and weight per cent burn loss in 1x4 dimension lumber

This graph shows that the weight loss of the combustion tests were greater in the samples that had less % water glass impregnated in the test sample. As the % water glass that was in the in the sample increased, the percent weight loss from the combustion test decreased.

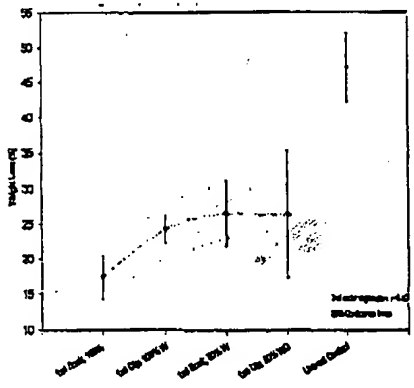


Figure 4. Weight loss all samples,

1x4 pine treated with water glass

This graph is a second order regression, and it shows the line connecting two data points as the regression line. The lines around the regression line shows that 95% of the time, the data will lie within those lines. The regression line does not connect with the control, because the control has much different results.

1X4 PRESSURE TREATED PINE - PROPANE FLAME TESTS:

Figures 5-6 present the results of propane flame tests of sodium silicate treated 1x4 pressure treated pine samples.

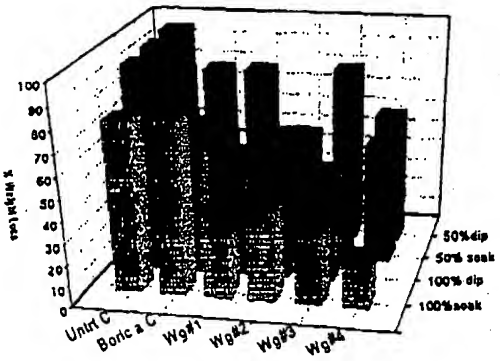


Figure 5. Weight loss of samples in flame tests with 1x4 pressure treated lumber

Figure 5 shows how great the 5 wt. loss was of the untreated control and the boric acid control, and the water glass treated samples. The data shows that in all cases, the water glass samples performed better than the boric acid control and better than the untreated control.

Propane Test for 1x4 pressure treated pine wood sample subjected to a 1-day dip in 100% sodium silicate:

Burn initiation (T_0): The flame from the propane tank began to reflect off the wood sample. The color of the fire was bright orange. The flame reflection extended 13 cm up from the base of the wood. The flame also began to burn up the right side slightly.

Burn Period ($T_{1\text{-}20}$): The flames continue to reflect off the sodium silicate, only reaching 15 cm high. The flames reach the small left side, where it is mostly unprotected. The fire spreads quickly up the side without much treatment, while the other sides continue to repel the attacks from the fire. Later on in the test period, the flame rose, and consumed most of the center of the wood sample.

Post burn period ($T_{20\text{-}35}$): Most of the center section of the wood and the right side has been burned away. There is a small chunk of wood that fell off in burning, but the rest of the missing wood is ash and debris. There was small evidence of the sodium silicate burning, there are 1-2 cm2 areas where the sodium silicate has bubbled up into foam, but the foam did no stop the spread of the flame. The part that is missing is 21 cm high and 6 cm wide. The color of the intact wood is black, but in some spots the original dark green color is visible.

Propane Flame Test for untreated control, 1x4 pressure treated pine, compared to dip, 100 % sodium silicate, pressure treated pine, 1x4:

Burn initiation (T_0): When the flame was applied to the wood, the wood burst into flame, with the fire reached above and beyond the top of the wood. The spread of the fire took place remarkably fast.

Burn period ($T_{1\text{-}20}$): The flames on the wood continued to grow and propagate. The flames spread up all sides of the wood. Slowly, the wood began losing its shape, ashes fell and the wood began to deteriorate.

Post burn period ($T_{20\text{-}35}$): After the propane tanks were removed, the sample continued to smolder and burn until,there was nothing left that it could burn. The cinders kept smoldering for a while, until they died out as well. The remains of the wood sample weighed only about 3% of the original weight. The remains of the sample could be collected in the bottom of a cup. There were no pieces of wood that could still hold a shape; it had all turned to ash. The color of the ash was a light gray.

Propane Test for 1x4 pressure treated pine wood sample subjected to a 7-day soak in 100% sodium silicate:

Burn initiation (T_0): When the flame first touched the wood sample, the flame reflected off the wood and turned bright orange. The wood sizzled and popped. The flame reflected 9 cm from the first point of contact.

Burn period ($T_{1\text{-}20}$): The flame stayed roughly around the same area where it had been when the test started. The flames did grow some, though. The flames spread soot and ash around to other parts of the wood. The wood kept its same shape throughout the burning.

Post burn period ($T_{20\text{-}35}$): The wood sample kept its basic same shape when it was taken away from the flame. Its burn area was a small portion on the bottom of the sample. Most of the sample is still good, firm wood. There is evidence of sodium silicate burning on the edge of the charred parts. The charred parts extended to a few cm short of the top of the wood. Surprisingly, the wood kept its shape.

Propane Flame Test for untreated control, 1x4 pressure treated pine, compared to 7-day soak, 100% sodium silicate, pressure treated pine, 1x4:

Burn initiation(T_0): When flame is first applied to the sample, the fire propagates quickly and starts to spread up the sides of the sample. The fire soon quickens, and begins to spread to other parts of the sample.

Burn period ($T_{1\text{-}35}$): The flames on the wood rose, and began to consume the whole sample. The flames extended above the sample, in the air, and the sample began to lose shape quickly. The flames continued to eat away at the burn sample even when the propane tanks were turned off.

Post burn period ($T_{20\text{-}35}$): After the wood sample was separated from the wood, the sample lost its shape and fell apart into a heap of ash. The ash is all that is left of the sample. The ash is all powder with no recognizable parts in it. The ash is dark gray, to light gray.

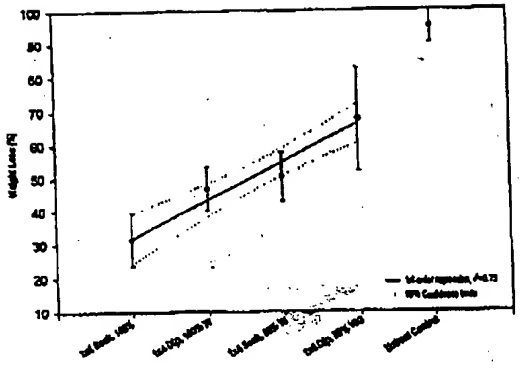


Figure 6. Weight loss all samples, 1x4 pressure treated pine treated with water glass

Figure 6 shows the % wt. loss compared to each treated sample. This graph is a first order regression which shows that as you lessen the % of water glass you treat the sample with, and shorten the amount of time the samples are introduced to the water glass, the % wt. loss increases.

2X4 PINE - PROPANE AND CANDLE FLAME TESTS:

Figure 7 presents the results of candle flame tests of sodium silicate treated 2x4 pine samples.

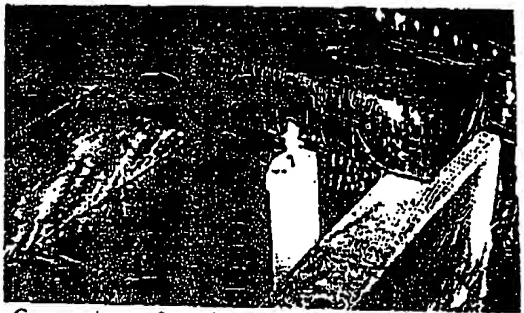


Figure 7. Comparison of results of burn tests with candle flame on treated and untreated 2x4 samples

Propane Flame Test for 2x4 spruce sample subjected to a 24-hour dip in 100% sodium silicate:

Burn initiation (T_0): The flame from the propane tank began to make an area of the wood glow. The area that was glowing was 1 inch in diameter. The sample made sizzling and popping noises, and around the burn area, white foam bubbled out of the sodium silicate.

Burn period ($T_{1\text{-}20}$): The flame from the propane tank spread about 3 cm around the initial burn site. No wood propagation occurred in this wood sample. Around and above the burn site, char expanded causing more sodium silicate to bubble up along the outside of the char area. No flame burned by itself on the wood. Any time that a flame would begin to grow it size, it would die down. Instead of burning, the area around the initial contact point, the area reddened, and glowed in the heat.

Post burn period ($T_{20\text{-}35}$): After the propane flame was removed from the test sample, the wood continued to smolder for a short while. The sample was only changed from the flame in the bottom 15.5 cm. At the contact point of the flame, there was a large crater, 4 cm wide, 3.5 cm long, and 2 cm deep. The walls of the crater are all black, with white foam at ground level of the crater. Above the crater, there is cracked char with a thin layer of sodium silicate foam on the top of it. The foam surrounds all sides of the char. No charring or burning

occurred at any of the small sides of the sample. The back side of the sample is completely clear of any burning or charring.

Propane Flame Test for 2x4 spruce untreated control sample, compared to dip, 100% sodium silicate:

Burn initiation (T_0): When the flame from the propane tank reached the wood, it created an area of charring with a 3 cm diameter from the initial point of contact. A small flame began to dance on the top of the char area, but died down with the first gust of wind.

Burn Period ($T_{1\text{-}29}$): The char area increased over time, and small flames would begin to burn, but the flames could not resist the wind. The propane flame did not create a fir that propagated on the wood, all it did was create an area of char, and allow the wood to glow with the heat.

Post burn period ($T_{30\text{-}33}$): After the propane flame was removed from the wood sample the flames died down quickly. The wood still smoldered, and gave off lots of smoke. The wood was only burned on the front side of the sample. There were two craters in the wood, and a large area of char surrounding them. The charred areas extended from the base of the wood sample to 19 cm above it. The char was a dark black and had many cracks in it.

COMPOSITE SAMPLES - PROPANE FLAME TESTS:

Figures 8-10 present the results of propane flame tests of sodium silicate treated composite wood samples.

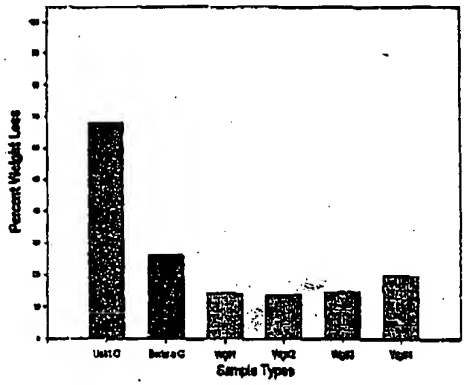


Figure 8. Fire retardant effect of water glass on plywood

Figure 8 shows the % wt. loss compared to the sample so plywood. The untreated control has a much greater % wt. loss than the boric acid or treated control. In this test run, the treated samples had a lower % wt. loss than either the boric acid control, or the untreated control.

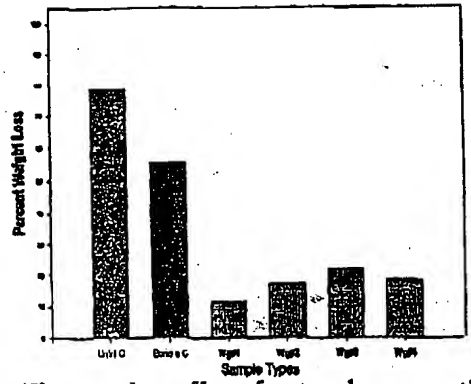


Figure 9. Fire retardant effect of water glass on particle board

Figure 9 shows the % wt. loss compared to the different sample types. This graph shows the large difference between the controls and the test samples. The test sample had a much lower % weight loss than either the boric acid control or the untreated control.

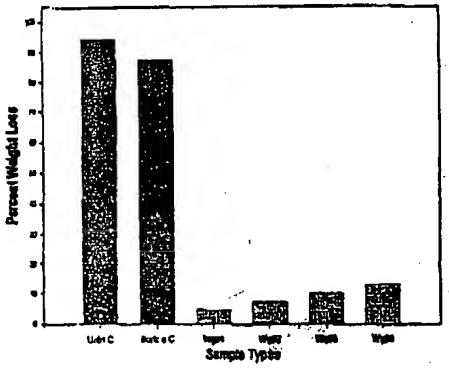


Figure 10. Fire retardant effect of water glass on wafer board

Figure 10 shows the % wt. loss compared to the different types of samples. In this test the treated samples had a much lower % wt. loss than either the boric acid or untreated control. The water glass treated samples have a much lower flame retardancy than either control.

CLOTH SAMPLES - CANDLE FLAME TESTS:

Figures 11-13 present the results of propane flame tests of sodium silicate treated cloth samples.

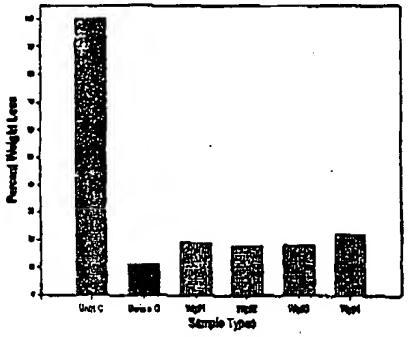


Figure 11. Fire retardant effect of water glass on cloth strips

This graph sows that the untreated control had almost 100% wt. loss. In this test, the boric acid sample had the lowest % weight loss. All of the treated samples had a much lower % wt. loss than the control.

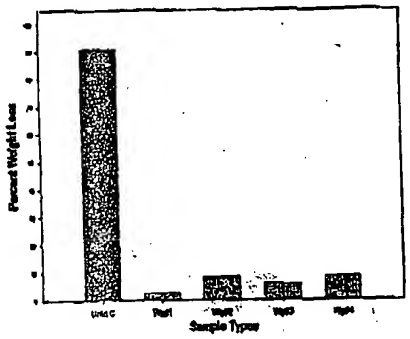


Figure 12. Fire retardant effect of water glass on slurried cloth strips

In this graph there is no boric acid sample. Tjis graph shows how dramatic the results are. the control had about a 90% wt. loss, and the samples, at most had about an 11% wt. loss

Candle Test-Fabric:

Treated sample: Charring in the spot directly in the flame, smoke production. Flame does not spread. The felt is getting cracks in the flame area. The area in direct contact with flame is getting bubbles. Smoke occurs only when in the flame. No flame propagation occurred in the test.

Control sample: The burning started to propagate on the sample immediately. The smoke given off was white. The flames reached about 2 inches off of the sample. The burning did not occur as fast as would have been forecasted. The sample did not catch fire as much as the charring just spread.

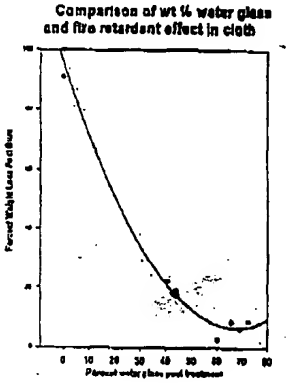


Figure 13. Comparison of weight per cent water glass and fire retardant effect in cloth

Figure 13 shows the 95% confidence limit lines, which shows that as the amount of water glass in the sample in creses, the % wt. loss decreases. This shows that the sodium silicate has a major effect on the burn characteristics of the samples.

PAPER SAMPLES - CANDLE FLAME TESTS:

Figures 14-18 present the results of propane flame tests of sodium silicate treated 1x4 pine samples.

Candle Test – Paper:

Treated sample: The flame darkens the paper, but doe not catch fire. The paper sizzles and cracks in response to the fire. The paper itself does not catch fire, but does release a lot of smoke. The area of char does not go past the initial

contact point with the paper. At the points on the paper that are in direct contact with the flame, It begins to redden, but does not catch fire. The paper thickens as heat is applied to it. It takes the fire 5 min 33 sec before it can do all of its work.

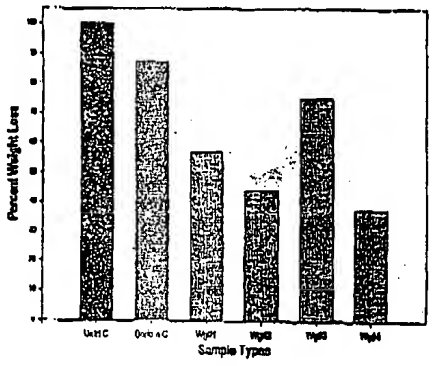


Figure 14. Fire retardant effect of water glass on paper

Figure 14 shows the % wt. loss compared to the different sample types. This test shows how the sodium silicate treated samples have a much less % wt. loss than the boric acid and untreated controls.

Figure 15 shows the % wt. loss compared to the different sample types. There is no boric acid control in this test. This test run shows how much greater wt. the control loses than the treaed samples. this graph is an excellent example of how the sodium silicate effect the burn characteristics.

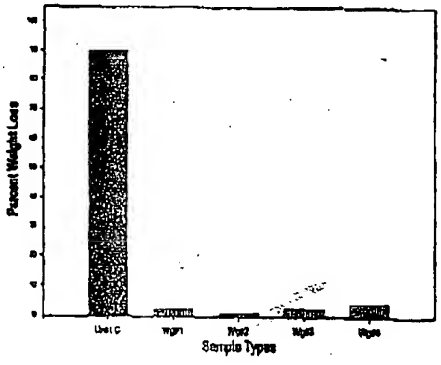


Figure 15. Fire retardant effect of water glass on slurried paper

Control sample: The flame started up the paper immediately, spreading quickly up the paper. The fire elevated to 1/2 of an inch above the paper, the total burn time for the paper to become consumed lasted 17 seconds. The final weight was too small to measure.

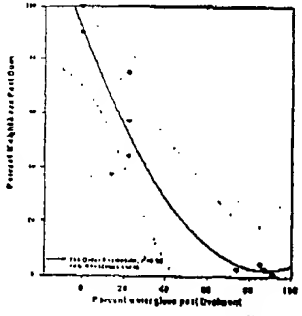


Figure 16. Comparison of weight percent water glass

and fire retardant effect in paper

Figure 16 shows % wt loss after burn, compared to the percent waterglass after treatment. The graph shows that as the amount of sodium silicate in the sample increases, the % wt. loss from burn decreases. This can show that sodium silicate has a positive effect on the burn characteristics of paper.

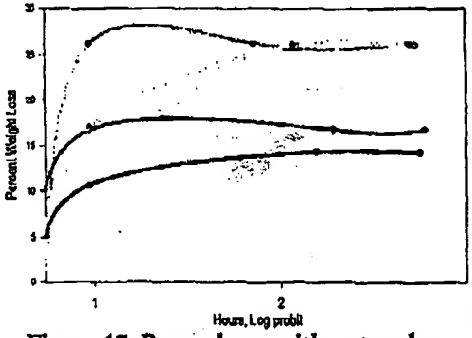


Figure 17. Paper slurry with water glass: per cent weight loss over time

Figure 17 shows the burn cycle over a 2 hour period. The graph shows that when the flame is first applied, weight loss increases rapidly. After about 20 min the weight loss begins to taper off and continues in an almost straight line.

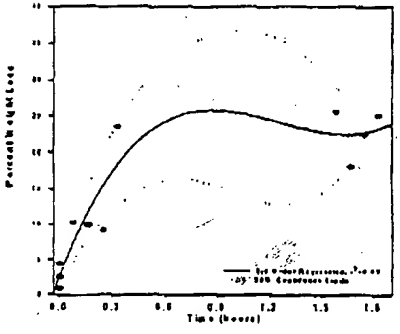


Figure 18. Paper slurry with water glass: percent weight loss over time

Figure 18 is similar to that of Figure 17. It shows the burn cycle of the flames in a 2 hour period. This graph is a third oreder regression, which shows the path of the burn characteristics.

1X4 PINE CUBES - TERMITE TESTS:

To test another benefit of sodium silicate wood treatment, I soaked small pieces of wood in sodium silicate and introduced them to termites to see if the same quality that makes the wood flame resistant would also make the wood termite resistant. I found that the termites did not like to be around the water glass treated wood, and they did not even like to be around the damp paper towels in the test samples, which may have contained small amounts of water glass. The termites located themselves in an area as far away from the treated samples as possible, even though the treated wood was their only food source. No wood consumption occurred.

SUMMARY OF RESULTS - ALL SAMPLES

Figures 19-21 and Tables 1-3 present comparisons of the results obtained with all samples tested.

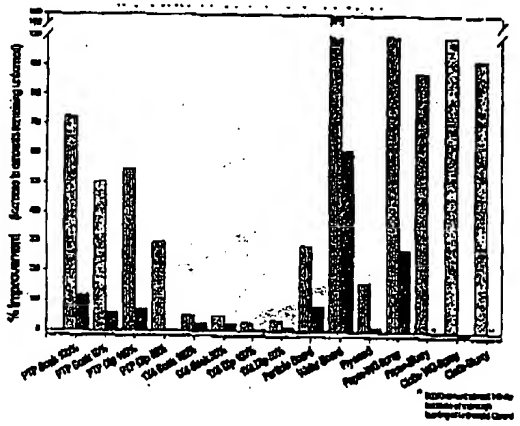


Figure 19. Comparison of water glass results to controls

Figure 19 shows the % improvement of the test sample over the control. In the graph, the blue lines represent the boric acid, and the green lines represent the sodium silicate treated samples. The graph shows that sodium silicate is a more effective fire retardant than boric acid/borax.

Figure 20. Comparison of boric acid results to untreated control

Figure 20 shows the % improvement of the boric acid samples over the control. This graph shows that the boric acid is a somewhat effective fire retardent treament.

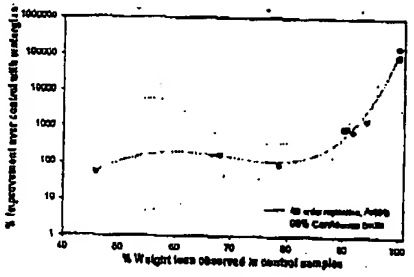


Figure 21. Relationship between increasing flammability in control samples and increasing effectiveness in water glass treated samples

Figure 21 shows that as the % wt. loss in the control samples increased, the % improvement over the control the treated samples were.

Table 1. Comparison of Water Glass and Untreated Control

Sample Type	Weight Loss Comparisons: Percentage reduction in weight loss	# times better than control	Percent better than control	Percent improvement	Comparisons of Amounts Unburned: Average amount unburned (control)	Average amount unburned (treated)	Number of times better than control	Percent improvement
1x4 Pressure-treated pine samples								
Soak-100% WG	59.73	2.97	297%	197	8.23	68	8.24	724%
Soak-50% WG	41.3	1.703	170%	70%	8.23	49.75	6.05	505%
Dip 100% WG	43.08	1.77	177%	77%	8.23	53.23	6.46	546%
Dip-50% WG	34.3	1.36	136%	36%	8.23	32.75	3.97	297%
1x4 Pine Samples (Not pressure treated)								
Soak-100% WG	38.85	2.66	266%	166%	54.1	82.63	1.53	53%
Soak-50% WG	37.1	2.44	244%	144%	54.1	81.5	1.5	50%
Dip 100% WG	15.63	1.32	132%	32%	54.1	69.73	1.28	28%
Dip 50% WG	19.65	1.77	177%	77%	54.1	73.75	1.36	36%
Composite Products								
Particle board	81.5	4.61	461%	361%	21.5	83	3.86	286%
Wafer board	83.45	10.78	1078%	978%	5.8	91.32	15.76	1477%
Plywood	32.13	4.38	438%	338%	32	84.13	2.63	163%
Paper and Cloth Products								
Paper Spray	46.63	1.87	187%	87%	.03	46.63	1554	155333%
Paper Slurry	87.4	34.61	3461%	3361%	10	97.4	9.74	874%
Cloth Spray	80.95	5.24	524%	424%	0.07	80.95	899	89864%
Cloth Slurry	84.49	14.38	1438%	1338%	9.2	93.69	10.18	918%

Table 2. Comparison of Water Glass and Boric Acid

Sample Type	Weight Loss Comparisons: Percentage reduction in weight loss	# times better than control	Percent better than control	Percent improvement	Comparisons of Amounts Unburned: Average amount unburned (control)	Average amount unburned (treated)	Number of times better than control	Percent improvement
1x4 Pressure treated pine samples								
Soak-100% WG	54.85	2.13	213%	113%	31.13	68	2.18	118%
Soak-50% WG	18.6	1.37	137%	37%	31.13	49.75	1.60	60%
Dip 100% WG	32.18	1.47	147%	47%	31.13	53.33	1.71	71%
Dip-50% WG	1.4	1.02	102%	2%	31.13	32.75	1.05	5%
1x4 Pine Samples (Not pressure treated)								
Soak-100% WG	17.4	2.00	200%	100%	63.23	82.63	1.26	26%
Soak-50% WG	13.97	1.83	183%	83%	63.23	81.2	1.24	24%
Dip 100% WG	4.5	1.15	115%	15%	63.23	69.73	1.07	7%
Dip 50% WG	8.52	1.35	135%	32%	63.23	73.75	1.13	13%
Composite Products								
Particle board	28.4	3.26	326%	226%	44.6	83	1.86	86%
Wafer board	78.25	9.93	993%	893%	12.9	91.32	7.08	608%
Plywood	10.13	1.64	164%	64%	74	84.13	1.14	14%
Paper and Cloth Products								
Paper Spray	34.13	1.64	164%	64%	12.5	46.63	3.73	273%
Paper Slurry	—	—	—	—	—	—	—	—
Cloth Spray	-7.95	0.58	58%	-42%	88.9	80.95	0.91	-9%
Cloth Slurry	—	—	—	—	—	—	—	—

Table 3. Comparison of Boric Acid and Untreated Control

	Weight Loss Comparisons				Comparisons of Amounts Unburned			
Sample Type	Percentage reduction in weight loss	# times better than control	Percent better than control	Percent improvement	Average amount unburned (control)	Average amount unburned (treated)	Number of times better than control	Percent improvement
1x4 Pressure treated pine samples								
Soak-100% WG	22.9	1.33	133%	33%	8.25	31.13	377	377%
Soak-50% WG	22.9	1.33	133%	33%	8.25	31.13	377	377%
Dip 100% WG	22.9	1.33	133%	33%	8.25	31.13	377	377%
Dip-50% WG	22.9	1.33	133%	33%	8.25	31.13	377	377%
1x4 Pine Samples (Not pressure treated)								
Soak-100% WG	11.13	1.33	133%	33%	34.1	63.23	1.3	30%
Soak-50% WG	11.13	1.33	133%	33%	34.1	63.23	1.3	30%
Dip 100% WG	11.13	1.33	133%	33%	34.1	63.23	1.3	30%
Dip 50% WG	11.13	1.33	133%	33%	34.1	63.23	1.3	30%
Composite Products								
Particle board	23.1	1.36	136%	36%	91.3	44.6	2.1	110%
Wafer board	7.1	1.08	108%	8%	5.8	12.9	2.22	122%
Plywood	42	2.41	241%	141%	32	74	2.31	131%
Paper and Cloth Products								
Paper Spray	12.5	1.14	114%	14%	0.03	12.3	416.66	41566%
Paper Slurry								
Cloth Spray	88.9	9.00	900%	800%	0.09	88.9	987.77	98677%
Cloth Slurry								

The percent weight loss for regular 1x4s and 2x4s was lower than for pressure treated pine. This was probably due to the fact that the results were obtained under different burn conditions. These tests were performed outdoors where it was windy and very cold, also only one torch was used with a very small flame. If I were to repeat the test using the conditions for the pressure treated pine samples, I would expect the results to be similar to those for pressure treated pine samples.

The data show that water glass treatment may be effective in preventing flame propagation throughout wood samples. Even though the wood will burn in areas in direct contact with hot flame, the flames will not spread. This will help to keep small fires from spreading into large ones.

In all samples tested, including standard building materials: 1x4s, 2x4s, and pressure treated 1x4s, treatment with water glass was found to cause a reduction in flame propagation and in total amount of wood combustion.

For all samples flame resistance tended to increase as the concentration of water glass increased.

The greatest difference between the treated samples and the control was found with samples that were highly flammable for example paper and cloth.

In addition, since most fires start with flammable materials inside a building such as with paper and drapery, the findings that flammability can be reduced by up to 90 % with the use of water glass, suggests that this substance may have potential for fire prevention in paper and cloth products.

In general, the more easily combustible the substance studied, the greater was the fire retardant effect of sodium silicate.

It was found that it was surprisingly difficult to get solid wood to burn, this was only accomplished when full force flames from the large nozzles of two blow torches were simultaneously directed onto 1x4 untreated pine samples. All of the samples burned more readily including pressure treated pine samples which burned thoroughly and easily. The most easily burned wood-based sample was wafer board which proved to be highly combustible.

Of all wood-based samples wafer board flame resistance was the most improved after treatment with water glass.

Sodium silicate, water glass, does appear to be an effective fire retardant chemical. This represents a new use for this chemical.

The following publications are herein incorporated in their entirety by reference.

1. Avento, J., Touval, I., 1985, Flame Retardants, An Overview, *in* Kirk-Othmer Concise Encyclopedia of Chemical Technology, John Wiley & Sons, New York, pp. 485-490.
2. Sienko, M., Plane, R., 1961, Chemistry, 2nd ed., McGraw-Hill Book Company Inc., New York.
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4. ASTM, 1993. Standard Methods for Flammability of Treated Paper and Paperboard, Designation D 777 - 93, ASTM, Philadelphia PA, 78-80.
5. ASTM, 1989. Standard Specification for Flame-Resistant Treated Paper and Paperboard, Designation D 4433, ASTM, Philadelphia PA, 588-589.
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9. ASTM, 1992. Standard Test Method for Laboratory Evaluation of Wood and other Cellulosic materials for Resistance to Termites, Designation D 3345- 74, ASTM, Philadelphia PA, 430-732.
10. ASTM, 1993. Standard Index of and Descriptions of Textile Heat and Flammability Test Methods and Performance Specifications, Designation D 4723- 90, ASTM, Philadelphia PA, 480 - 485.